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(54) **SYSTEM AND METHOD TO MAINTAIN TARGET MATERIAL IN DUCTILE STATE**

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H01J 35/00 (2006.01)

(52) **U.S. Cl.** **378/127**; 378/111; 378/134

(58) **Field of Classification Search** 378/111, 378/112, 113, 127, 134
See application file for complete search history.

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(57) **ABSTRACT**

An x-ray tube includes a frame, an anode for generating x-rays disposed within the frame, a cathode disposed within the frame, where the cathode is configured to selectively emit an electron beam toward the anode, and at least one heating element disposed within the frame and configured to heat a portion of the anode.

20 Claims, 5 Drawing Sheets

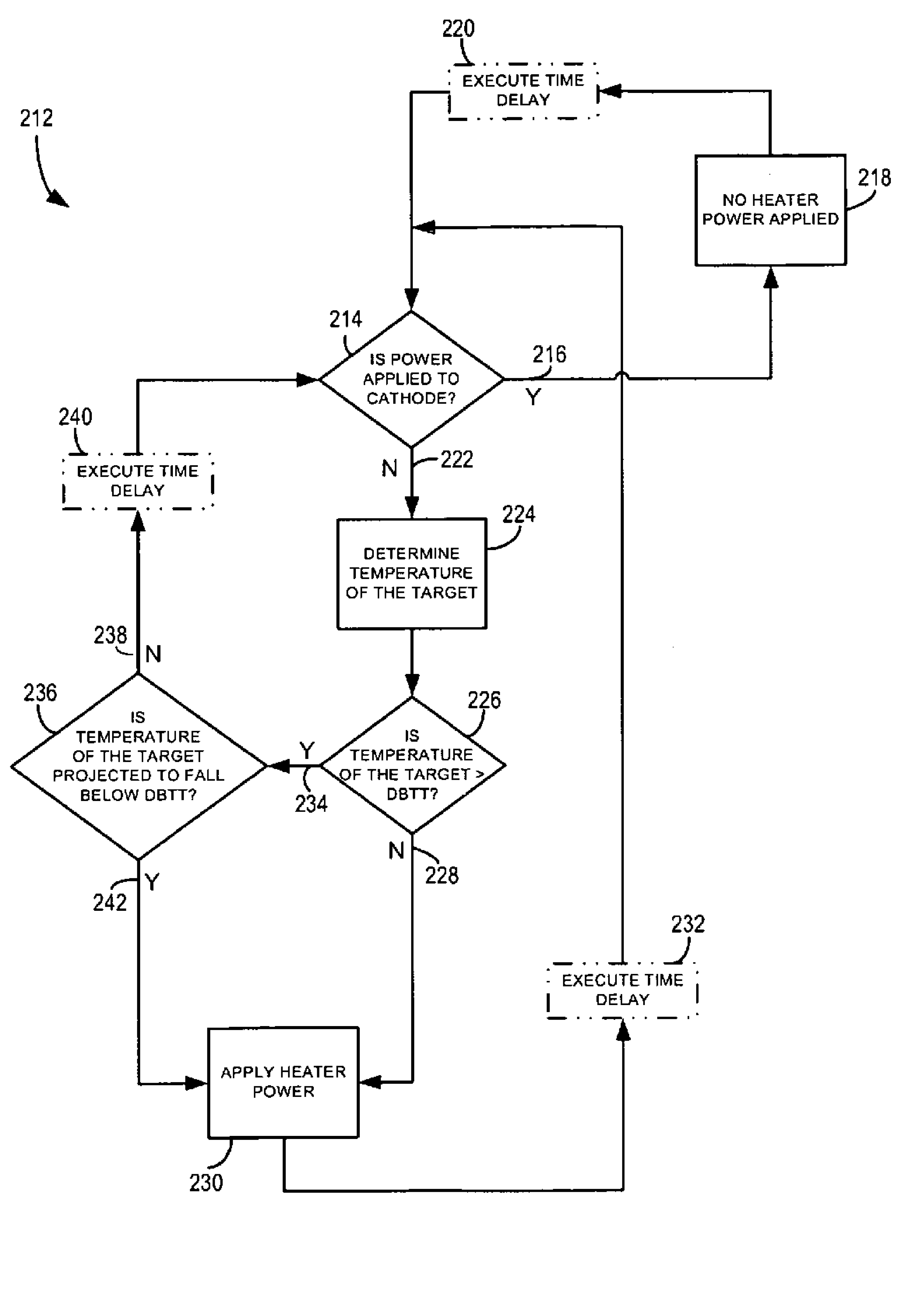
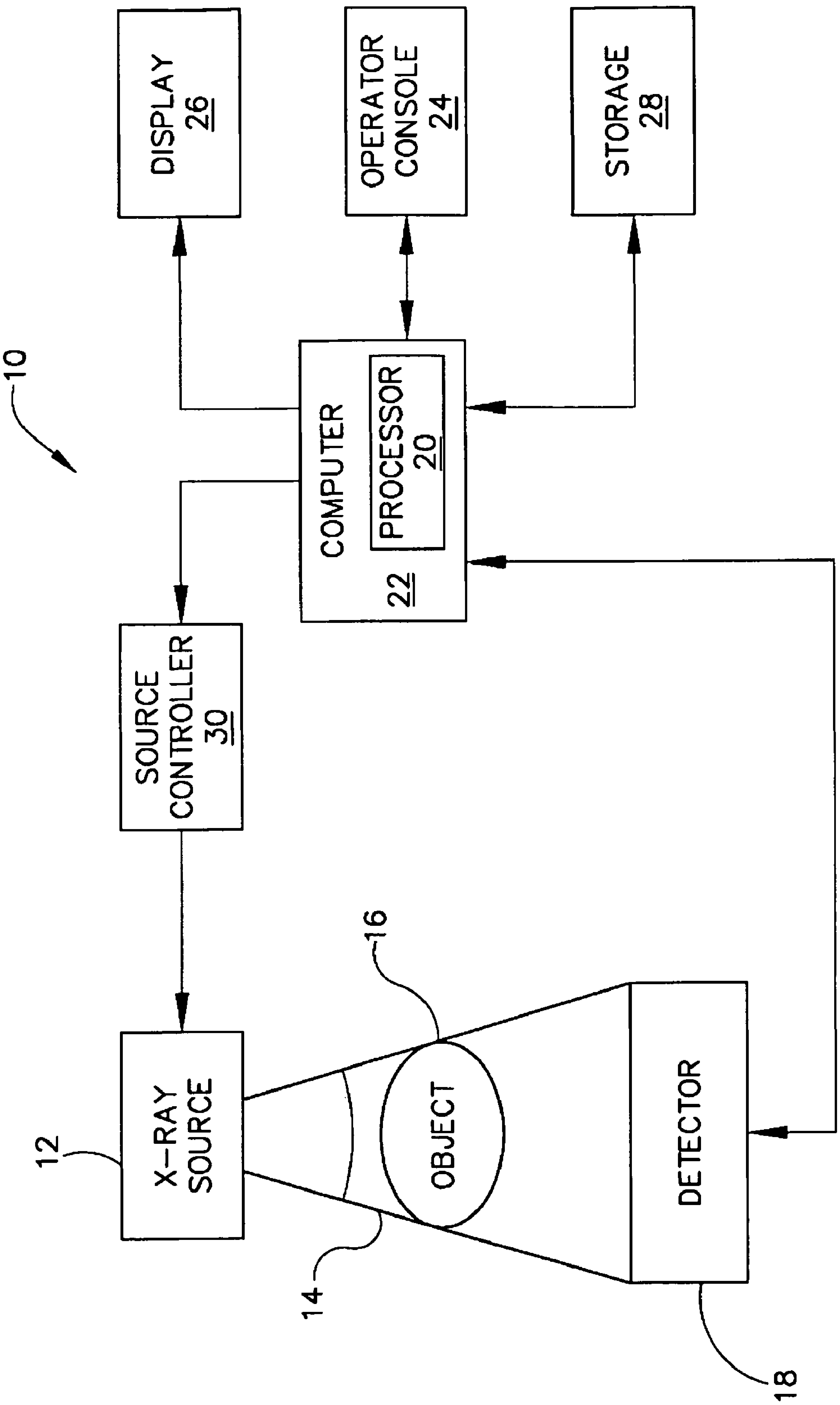
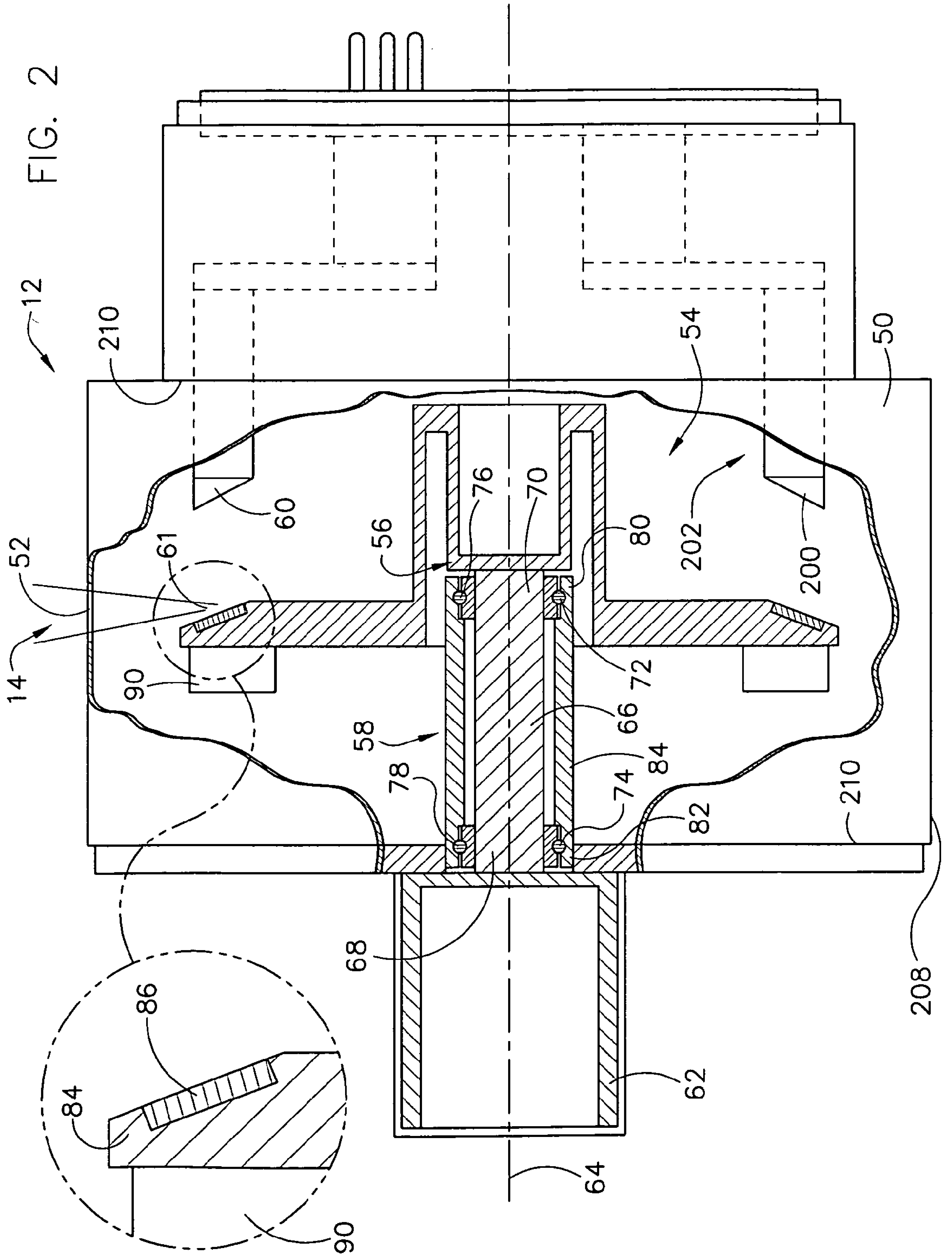


FIG. 1



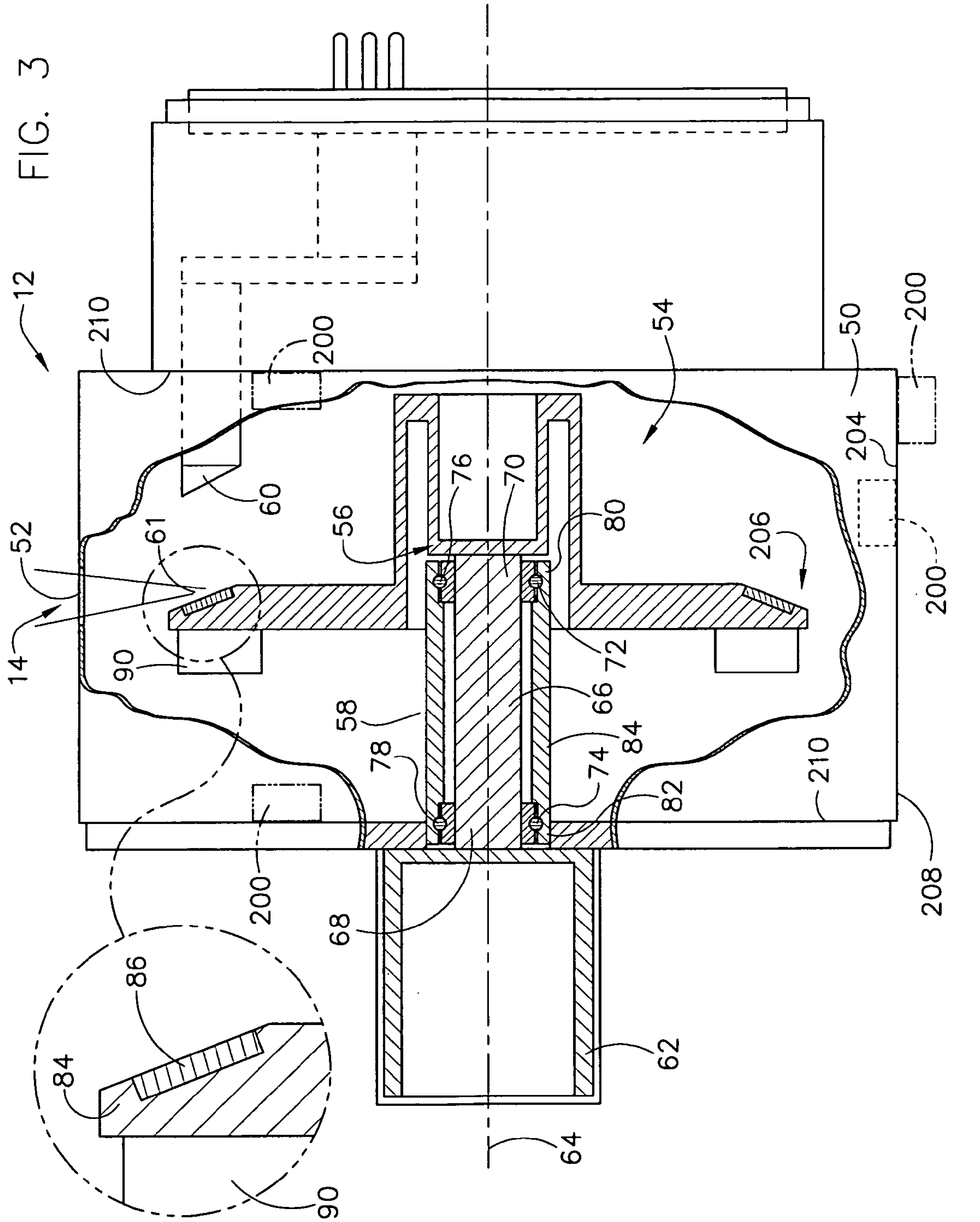
DISPLAY 26
OPERATOR CONSOLE 24
STORAGE 28
10
COMPUTER
PROCESSOR 20
22
SOURCE CONTROLLER 30
16
12
X-RAY SOURCE
OBJECT
DETECTOR
14
18



12
210
54
50
56
76
70
80
202
200
60
52
61
14
90
72
66
58
84
78
74
82
210
68
208
86
84
62
90
64

FIG. 2

FIG. 3


12
210
200
54
50
200
204
60
76
70
56
80
206
200
52
61
14
90
72
66
58
84
78
74
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82
200
68
208
86
84
62
64
90

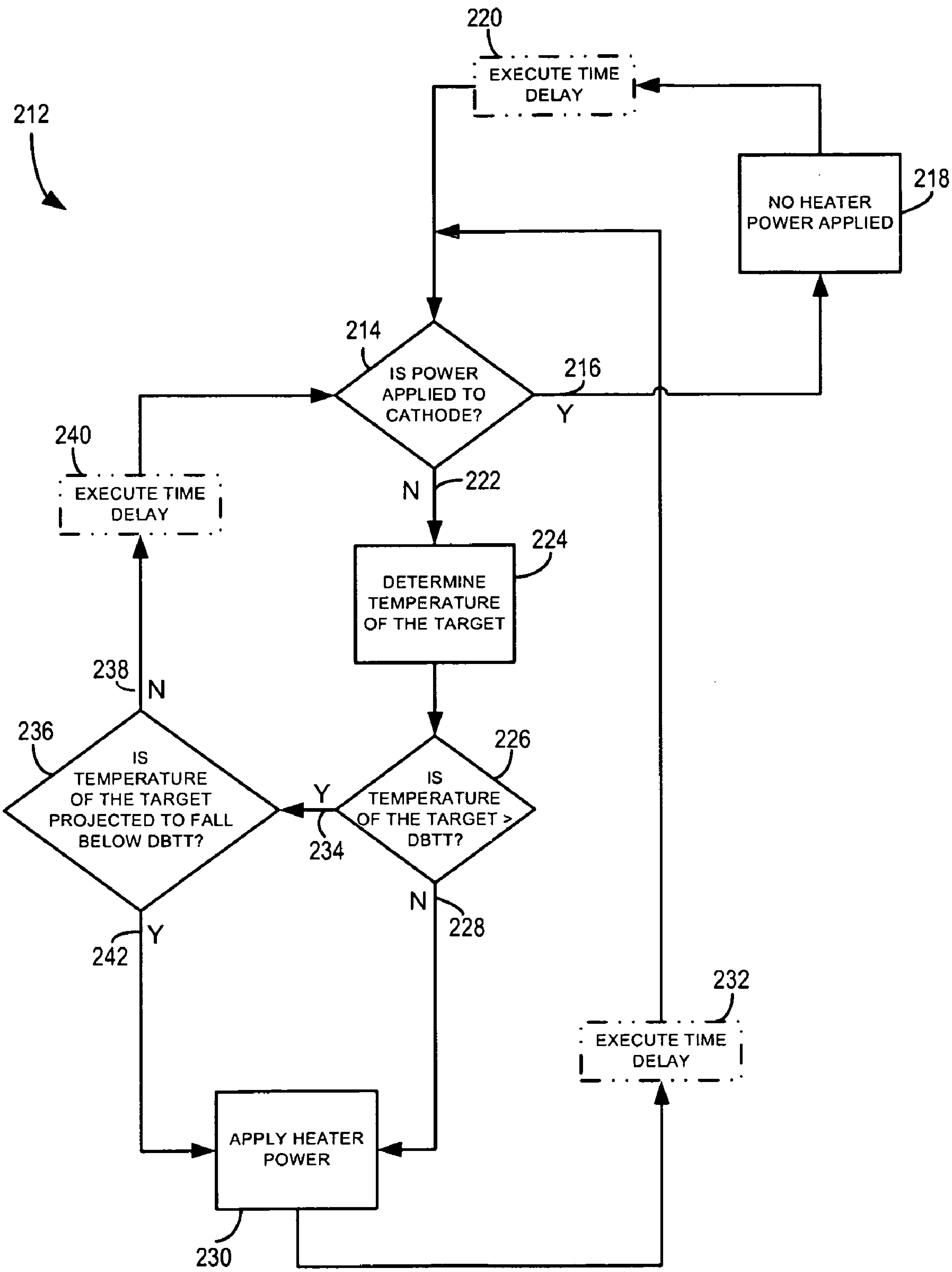
212
220
EXECUTE TIME DELAY
218
NO HEATER POWER APPLIED
214
IS POWER APPLIED TO CATHODE?
216
Y
N
222
224
DETERMINE TEMPERATURE OF THE TARGET
240
EXECUTE TIME DELAY
238
N
236
IS TEMPERATURE OF THE TARGET PROJECTED TO FALL BELOW DBTT?
Y
234
226
IS TEMPERATURE OF THE TARGET > DBTT?
N
228
Y
242
232
EXECUTE TIME DELAY
APPLY HEATER POWER
230

FIG. 4

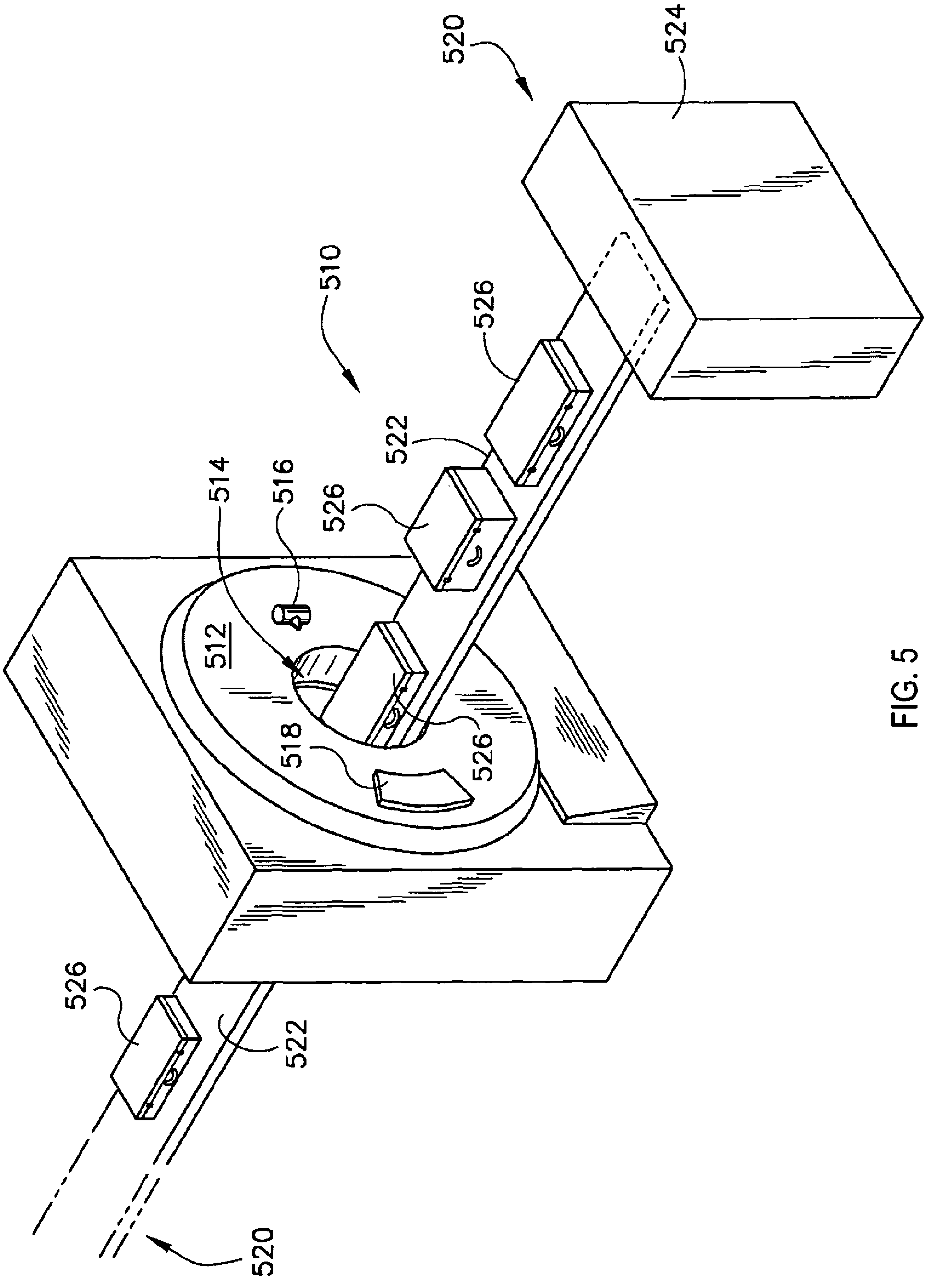

FIG. 5

SYSTEM AND METHOD TO MAINTAIN TARGET MATERIAL IN DUCTILE STATE

BACKGROUND OF THE INVENTION

The invention relates generally to x-ray tubes and, more particularly, to an apparatus for x-ray generation and a method of fabrication.

X-ray systems typically include an x-ray tube, a detector, and a bearing assembly to support the x-ray tube and the detector. In operation, an imaging table, on which an object is positioned, is located between the x-ray tube and the detector. The x-ray tube typically emits radiation, such as x-rays, toward the object. The radiation typically passes through the object on the imaging table and impinges on the detector. As radiation passes through the object, internal structures of the object cause spatial variances in the radiation received at the detector. The detector then emits data received, and the system translates the radiation variances into an image, which may be used to evaluate the internal structure of the object. One skilled in the art will recognize that the object may include, but is not limited to, a patient in a medical imaging procedure and an inanimate object as in, for instance, a package in an x-ray scanner or computed tomography (CT) package scanner.

X-ray tubes include a rotating anode structure for the purpose of distributing the heat generated at a focal spot. The anode is typically rotated by an induction motor having a cylindrical rotor built into a cantilevered axle that supports a disc-shaped anode target and an iron stator structure with copper windings that surrounds an elongated neck of the x-ray tube. The rotor of the rotating anode assembly is driven by the stator. An x-ray tube cathode provides a focused electron beam that is accelerated across a cathode-to-anode vacuum gap and produces x-rays upon impact with the anode. Because of the high temperatures generated when the electron beam strikes the target, the anode assembly may be rotated at a high rotational speed.

Between periods of x-ray production and periods of idle, the target material may experience a wide range of temperatures as it cools from operating temperature to room temperature. Within this wide range of temperatures, the target material may reach a temperature that represents the transition between a hot ductile state and a relatively cool brittle state, which may be referred to as a ductile-brittle transition temperature (DBTT). After a period of non-use, a warm-up scan may be used to preheat the target. A preheating scan allows the target to transition from the cooler brittle state to the warmer ductile state prior to high-power imaging protocols, thus reducing stress on the target material. However, due to operator error or scheduling requirements of the system, the preheating scan may be skipped, and the target material may drop below the DBTT, thus subjecting the target material to undesired stress and shortened target life.

Therefore, it would be desirable to have a method and apparatus to maintain an x-ray tube target within a desired temperature range and above the DBTT such that an imaging scanner may be used on demand without the need to perform a preheating scan.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides a system and method to maintain a selected portion of an x-ray tube anode in a ductile state.

According to one aspect of the invention, an x-ray tube includes a frame, an anode for generating x-rays disposed within the frame, a cathode disposed within the frame, where the cathode is configured to selectively emit an electron beam toward the anode, and at least one heating element disposed within the frame and configured to heat a portion of the anode.

In accordance with another aspect of the invention, a method of fabricating an electromagnetic energy source includes positioning a cathode to emit a primary electron beam toward a target. The method further includes positioning a heater to apply heat to a portion of the target to maintain the portion of the target above a specified temperature when the cathode is not emitting the primary electron beam.

Yet another aspect of the invention includes an imaging system having a rotatable gantry, which has a detector and an x-ray tube mounted thereto. The x-ray tube includes a structure enclosing a cavity, a target positioned within the cavity, a cathode positioned within the cavity and configured to direct current from the cathode to the target, and a heat source located remotely from the cathode.

Various other features and advantages of the invention will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate one preferred embodiment presently contemplated for carrying out the invention.

In the drawings:

FIG. **1** is a block diagram of an imaging system that can benefit from incorporation of an embodiment of the invention.

FIG. **2** is a cross-sectional view of an x-ray tube useable with the system illustrated in FIG. **1** according to an embodiment of the invention.

FIG. **3** is a cross-sectional view of an x-ray tube useable with the system illustrated in FIG. **1** according to another embodiment of the invention

FIG. **4** is a flowchart of a target heating process according to an embodiment of the invention.

FIG. **5** is a pictorial view of a CT system for use with a non-invasive package inspection system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** is a block diagram of an embodiment of an imaging system **10** designed both to acquire original image data and to process the image data for display and/or analysis in accordance with the invention. It will be appreciated by those skilled in the art that the invention is applicable to numerous medical imaging systems implementing an x-ray tube, such as an x-ray system, a vascular system, and a mammography system. Other imaging systems such as CT systems and digital radiography systems, which acquire image three dimensional data for a volume, also benefit from the invention. The following discussion of x-ray system **10** is merely an example of one such implementation and is not intended to be limiting in terms of modality.

As shown in FIG. **1**, x-ray system **10** includes an x-ray source **12** configured to project a beam of x-rays **14** through an object **16**. Object **16** may include a human subject, pieces of baggage, or other objects desired to be scanned. X-ray source **12** may be a conventional x-ray tube producing x-rays having a spectrum of energies that range, typically, from 30 keV to 200 keV. The x-rays **14** pass through object **16** and, after being attenuated by the object, impinge upon a detector **18**. Each detector in detector **18** produces an analog electrical signal that represents the intensity of an impinging x-ray beam, and hence the attenuated beam, as it passes through the object **16**. In one embodiment, detector **18** is a scintillation based detector, however, it is also envisioned that direct-conversion type detectors (e.g., CZT detectors, etc.) may also be implemented.

A processor **20** receives the signals from the detector **18** and generates an image corresponding to the object **16** being scanned. A computer **22** communicates with processor **20** to enable an operator, using operator console **24**, to control the scanning parameters and to view the generated image. That is, operator console **24** includes some form of operator interface, such as a keyboard, mouse, voice activated controller, or any other suitable input apparatus that allows an operator to control the x-ray system **10** and view the reconstructed image or other data from computer **22** on a display unit **26**. Additionally, console **24** allows an operator to store the generated image in a storage device **28** which may include hard drives, floppy discs, compact discs, etc. The operator may also use console **24** to provide commands and instructions to computer **22** for controlling a source controller **30** that provides power and timing signals to x-ray source **12**.

Moreover, the invention will be described with respect to use in an x-ray tube. However, one skilled in the art will further appreciate that the invention is equally applicable for other systems that may benefit from reducing a number of heating cycles wherein a material transitions above and below a DBTT.

FIG. **2** illustrates a cross-sectional view of an x-ray tube **12** that can benefit from incorporation of an embodiment of the invention. The x-ray tube **12** includes a casing **50** having a radiation emission passage **52** formed therein. The casing **50** encloses a vacuum **54** and houses an anode or target **56**, a bearing assembly **58**, a cathode **60**, and a rotor **62**. X-rays **14** are produced when high-speed electrons from a primary electron beam are suddenly decelerated when directed from the cathode **60** to the target **56** via a potential difference therebetween. In high voltage CT applications, the potential difference between the cathode **60** and target **56** may be, for example, 60 thousand volts or more. In other applications, the potential difference may be lower. The electrons impact a material layer or target track **86** at focal point **61** and x-rays **14** emit therefrom. The point of impact at focal point **61** is typically referred to in the industry as the focal spot. The x-rays **14** emit through the radiation emission passage **52** toward a detector array, such as detector **18** of FIG. **1**. In high voltage CT applications, to avoid overheating the target **56** from the electrons, the target **56** is rotated at a high rate of speed about a centerline **64** at, for example, 90-250 Hz. In lower voltage applications, the target **56** may remain stationary.

The bearing assembly **58** includes a center shaft **66** attached to the rotor **62** at first end **68** and attached to the target **56** at second end **70**. A front inner race **72** and a rear inner race **74** rollingly engage a plurality of front balls **76** and a plurality of rear balls **78**, respectively. Bearing assembly **58** also includes a front outer race **80** and a rear outer race **82** configured to rollingly engage and position, respectively, the plurality of front balls **76** and the plurality of rear balls **78**. Bearing assembly **58** includes a stem **83** which is supported by the x-ray tube **12**. A stator (not shown) is positioned radially external to and drives the rotor **62**, which rotationally drives target **56**. While FIG. **2** depicts a rotatable target **56**, it is also contemplated that target **56** may be configured to remain stationary during an imaging application. The target **56** includes a target substrate **84**, having target track **86** therein. A heat storage medium **90**, such as graphite, may be used to sink and/or dissipate heat built-up near the target track **86**.

FIG. **2** further illustrates a heat source **200** configured as an electron source (such as a second cathode) according to an embodiment of the invention. In an embodiment where heat source **200** is an electron source, heat source **200** may be located at a position **202** proximate the target **56** and configured to accelerate electrons toward the target **56** to cause heating therein, by passing a current through, for instance, a metal piece such as tungsten, of heat source **200** while applying a voltage between target **56** and heat source **200**. In such an embodiment, heat source **200** may be controlled and electrons may be accelerated toward the target **56** using a low voltage, for example 10 KeV or less. One skilled in the art will recognize that any voltage may be applied that will allow heat source **200** to accelerate electrons toward the target **56** using a diffuse beam, and the applied voltage may be selected to avoid x-rays from being generated from the target **56**.

Heat source **200** may also be an induction heater or a radiant heater, and the like, located at various positions within the x-ray tube **12**, according to embodiments of the invention. As shown in FIG. **3**, heat source **200** may be positioned on or within the x-ray tube **12** to generally apply heat to the target **56** or to direct heat to a desired location on the target **56**, such as the target track **86**, as an example. In a preferred embodiment, heat source **200** is positioned on an interior surface **204** of the casing **50** to direct heat towards an outside edge **206** of the target **56**. Possible alternative locations for the heat source **200** include, but are not limited to, an external surface **208** of the x-ray tube **12** and an internal surface **210** of the x-ray tube **12**.

Although FIGS. **2** and **3** illustrate heat source **200** at several discrete locations, it is contemplated that heat source **200** may be positioned at any location either on the casing **50** or within the x-ray tube vacuum **54** so as to heat the target **56** to a desired temperature. Furthermore, multiple heat sources **200** may be positioned on or within the x-ray tube **12** to achieve a desired temperature distribution within the target **56** or target track **86**.

According to embodiments of the invention, heat may be applied to the target **56** according to a technique **212** as illustrated in FIG. **4**. Technique **212** maintains a selected portion of the target **56** in a ductile state by selectively heating the target **56** of FIGS. **2** and **3** in order to maintain the temperature of either the entire target **56**, or a selected portion thereof, above the DBTT. According to an exemplary embodiment of the invention, technique **212** maintains the temperature of the target track **86** of FIGS. **2** and **3** above the DBTT of the target track material. In one embodiment, technique **212** may regulate the temperature of the target **56**, or more particularly the target track **86** as an example, by selectively controlling rotation of the target **56** while applying power to heat source **200** of FIGS. **2** and **3**. In another embodiment, technique **212** may selectively apply power to multiple heaters **200** of x-ray tube **12** in order to achieve or maintain a desired temperature distribution in the target **56**. According to another embodiment of the invention, technique **212** may be applied to a cold target as a tube-warming protocol to heat target **56** above the DBTT.

Technique **212** begins at step **214** by determining whether power is being applied to the cathode **60**. If power is being applied to cathode **60** of FIGS. **2** and **3** **216**, then technique **212** transitions to step **218** and no power is applied to the heat source **200**. At optional step **220**, technique **212** executes a time delay prior to returning to step **214**, which may avoid continuous looping in, for instance a computer program, while heater power is applied to cathode **60**. Technique **212** then returns control to step **214** to determine anew if power is being applied to the cathode **60**. In this fashion, technique **212** may monitor power directed toward the target and, if power is applied via the cathode, then no power is applied via the heater.

If power is not being applied **222** to the cathode **60**, as determined at step **214**, technique **212** continues to step **224** and the temperature of, for instance, the target track **86** is determined. Such determination may be via known algorithms that calculate or estimate a temperature of a target based on recently applied power thereto. At step **226**, if the temperature of the target track **86** is not above the DBTT **228**, such as during a period where the x-ray system is not in use or prior to tube warm-up, power is applied to the heat source **200** at step **230**. In this instance, technique **212** may serve as a tube warm-up protocol and a total amount of energy input is calculated, accordingly. Following the application of power at step **230**, technique **212** may enter an optional step **232** after which technique **212** cycles back to step **214** to determine if power has been applied to cathode **60** in the time period since the temperature of the target track **86** was last determined. At steps **224** and **226**, technique **212** again determines the temperature of the target track **86** and analyzes whether the temperature of the target track **86** is greater than the DBTT of the target track material to determine whether the applied heater power is sufficient. If the temperature of the target track **86** is below the DBTT **228**, power remains, or alternately is again applied to the heater at step **230**. Technique **212** continues to cycle between steps **224**, **226**, **230**, through optional step **232**, and back to step **214** until the temperature of the target track **86** is above the DBTT.

In an alternate path of technique **212**, if at step **226** the temperature is determined to be above the DBTT **234**, control moves to step **236** to determine whether the temperature is projected to fall below the DBTT. At step **236**, technique **212** may take into consideration such factors as the temperature difference between the target track **86** and the DBTT, the temperature of the target **56**, the ambient temperature, the estimated remaining idle time before power is to be applied to the cathode **60**, the configuration of the x-ray tube **12**, cooling time constants, and the like. If, at step **236**, the temperature of the target track **86** is not projected to fall below the DBTT **238**, technique **212** cycles back to step **214** to determine whether power has been applied to the cathode **60**. Prior to returning to step **214**, technique **212** may enter optional wait step **240**, wherein technique **212** executes a time delay before determining whether power is applied to the cathode **60**. If the temperature of the target track **86** is projected to fall below the DBTT **242**, however, technique **212** again applies power to the heater at step **230**. After applying power to the heater, technique **212** cycles back to step **214** to determine if power is applied to the cathode **60**, and if not **222**, the temperature of the target track **86** is determined anew at step **224**.

The amount and timing of the power applied to the heat source **200** at step **230** may be controlled based on numerous input parameters, including the determined temperature of the target **56** or target track **86**, ambient conditions, the configuration of the x-ray tube, the construction and material properties of the target **56**, and the like. Thus, in embodiments of the invention, power may be applied in intermittent pulses, or may be continuously applied, while the algorithm operates and cycles until the temperature is above the DBTT.

As such, technique **212** may be applied to an x-ray tube as a tube-warming procedure or to maintain a selected portion of the x-ray tube at a desired temperature between scans of an imaging device. If the target temperature is below the DBTT **228**, such as when starting imaging system **10** when cold, technique **212** will apply heater power **224** until the target temperature is above the DBTT **234**. If the target temperature is above the DBTT **234** but between scans as an example, technique **212** may also apply power to the heater **224** if the temperature is projected to fall below the DBTT **242**. And, if power is being applied via a cathode **216**, technique **212** will refrain from applying heater power and cycle or delay until no cathode power is applied. Accordingly, technique **212** will heat and maintain a target above the DBTT, thus minimizing the number of thermal cycles therethrough.

Referring now to FIG. **5**, package/baggage inspection system **510** includes a rotatable gantry **512** having an opening **514** therein through which packages or pieces of baggage may pass. The rotatable gantry **512** houses an x-ray energy source **516** as well as a detector assembly **518** having scintillator arrays comprised of scintillator cells. A conveyor system **520** is also provided and includes a conveyor belt **522** supported by structure **524** to automatically and continuously pass packages or baggage pieces **526** through opening **514** to be scanned. Objects **526** are fed through opening **514** by conveyor belt **522**, imaging data is then acquired, and the conveyor belt **522** removes the packages **526** from opening **514** in a controlled and continuous manner. As a result, postal inspectors, baggage handlers, and other security personnel may non-invasively inspect the contents of packages **526** for explosives, knives, guns, contraband, etc.

According to one aspect of the invention, an x-ray tube includes a frame, an anode for generating x-rays disposed within the frame, a cathode disposed within the frame, where the cathode is configured to selectively emit an electron beam toward the anode, and at least one heating element disposed within the frame and configured to heat a portion of the anode.

In accordance with another aspect of the invention, a method of fabricating an electromagnetic energy source includes positioning a cathode to emit a primary electron beam toward a target. The method further includes positioning a heater to apply heat to a portion of the target to maintain the portion of the target above a specified temperature when the cathode is not emitting the primary electron beam.

Yet another aspect of the invention includes an imaging system having a rotatable gantry, which has a detector and an x-ray tube mounted thereto. The x-ray tube includes a structure enclosing a cavity, a target positioned within the cavity, a cathode positioned within the cavity and configured to direct current from the cathode to the target, and a heat source located remotely from the cathode.

The invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims.

What is claimed is:

1. An x-ray system comprising:

an x-ray tube comprising:

a frame;

an anode disposed within the frame;

a cathode disposed within the frame, the cathode configured to selectively emit an electron beam toward the anode; and

at least one heating element disposed within the frame and configured to heat a portion of the anode; and

an x-ray controller configured to:

estimate a temperature of the anode using an algorithm that includes power previously applied thereto;

project when the anode is expected to fall below a ductile-brittle transition temperature (DBTT) based on the estimated temperature;

calculate an amount of power to be applied to heat the anode above the DBTT; and

apply the calculated amount of power to the at least one heating element.

2. The x-ray system of claim **1** wherein the at least one heating element is configured to selectively heat the portion of the anode to a temperature above the DBTT of the anode when the cathode is not emitting the electron beam.

3. The x-ray system of claim **1** wherein the at least one heating element comprises a plurality of heating elements disposed within the frame, each of the plurality of heating elements configured to heat the anode.

4. The x-ray system of claim **3** wherein the plurality of heating elements is positioned within the frame such that an approximately uniform temperature distribution is maintained within the anode.

5. The x-ray system of claim **1** wherein the at least one heating element is configured to heat one of a top surface, an outside edge, and a bottom surface of the anode.

6. The x-ray system of claim **1** wherein the at least one heating element is one of a radiant heater and an inductive heater.

7. The x-ray system of claim **1** wherein the at least one heating element is a cathode that is configured to emit electrons toward the anode as a diffuse beam at a voltage below which x-rays are produced.

8. A method of fabricating an electromagnetic energy source comprising:

positioning a cathode to emit a primary electron beam toward a target;

positioning a heater to apply an amount of heat to a portion of the target to maintain the portion of the target above a specified temperature when the cathode is not emitting the primary electron beam; and

providing a control algorithm for the heater, wherein the control algorithm is configured to estimate a temperature of the target, project when the temperature is expected to fall below a ductile-brittle transition temperature (DBTT), and calculate the amount of heat to apply to the portion of the target based on the estimation.

9. The method of claim **8** wherein positioning the heater to apply heat to the portion of the target above the specified temperature comprises heating the portion of the target above the ductile-brittle transition temperature of the target.

10. The method of claim **8** comprising coupling a processor to the heater and configuring the processor to operate the control algorithm.

11. The method of claim **10** comprising configuring the algorithm to selectively control a rotation of the target.

12. The method of claim **11** comprising configuring the algorithm to rotate the target while applying the heat to the portion of the target.

13. The method of claim **8** comprising configuring the heater to apply one of inductive heat and irradiative heat.

14. The method of claim **8** comprising configuring the heater to emit a secondary electron beam toward the target.

15. The method of claim **14** comprising configuring a processor to limit an amount of voltage supplied to the heater to avoid causing x-ray generation from the target.

16. An x-ray imaging system comprising:

a rotatable gantry;

a detector mounted to the rotatable gantry;

an x-ray tube mounted to the rotatable gantry, the x-ray tube comprising:

a structure enclosing a cavity;

a target positioned within the cavity;

a primary cathode positioned within the cavity and configured to direct current from the primary cathode to the target; and

a heat source located remotely from the primary cathode; and

a controller configured to:

estimater whether a temperature of the target is projected to fall below a ductile-brittle transition temperature (DBTT) if no power were to be applied to the primary cathode; and

apply power to the heat source to heat the target above the DBTT.

17. The system of claim **16** wherein the controller is configured to control energy applied to the heat source sufficient to maintain the target above a desired temperature.

18. The system of claim **17** wherein the desired temperature is a temperature above which a portion of the target is in a ductile state.

19. The system of claim **16** wherein the heat source is a secondary cathode mounted within the cavity.

20. The system of claim **19** comprising a generator configured to apply a voltage between the heat source and the target, wherein the voltage is less than 10 KeV.

* * * * *